THE BEARING OF THE STRATIGRAPHIC HISTORY AND INVERTEBRATE FOSSILS ON THE AGE OF THE ANTHRACOLITHIC[1] ROCKS OF KANSAS AND OKLAHOMA[2]

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The present interest in this subject is such as to warrant a brief review of the broader features as determined by the preliminary survey of the data at hand with regard to the age of the Kansas-Oklahoma rocks, before completing the final work upon them, to give an idea of the present status of the problem and suggest some of the larger features to be worked out.

I wish to acknowledge the assistance and co-operation of Professor C. N. Gould and through him of the Oklahoma Survey, which have contributed much to both data and suggestion, as well as material aid in pursuing these studies. For the privilege of carrying on my Kansas studies I am indebted to Dr. Haworth and the Kansas Survey. This manuscript has been submitted to Professors Haworth, Gould, and Prosser for their suggestions and criticisms, which have been incorporated. The general considerations have been freely discussed with Professor Cumings, and he has also read the manuscript and offered valuable suggestions.

In order to arrive at a comprehensive understanding of the invertebrate fauna of the rocks supposed to be of Permian age in the western Mississippi valley it is necessary to understand the stratigraphic history and the nature and range of the faunas of the underlying rocks as well. The discussion of this subject forms a necessary introduction to the Permian question.

[1] This term was introduced by Waagen and he has been followed by Diener of the Indian Survey; it is used to designate the Carboniferous and Permian deposits under a single head, when it is desirable to refer to them in that way.

[2] Published by permission of the state geologists of Kansas and Oklahoma. A portion of this paper was read at the Baltimore meeting of the Geological Society of America.

STRATIGRAPHIC CONSIDERATIONS

Several years ago it was discovered that the Cherokee shales were not the oldest deposits of the western Coal Measures or Pennsylvanian rocks. While it was known that the unconformity between these shales and the Mississippian rocks below was a profound one, yet its true significance was not realized until the discovery in Arkansas and eastern Oklahoma of a great series of underlying rocks of Pennsylvanian—Lower Coal Measures—age. The result of the discovery is to restore the Lower Coal Measures to the trans-Mississippi section, leaving the Cherokee shales and perhaps some associated strata representing the Middle Coal Measures—"Middle Upper Carboniferous" of European geologists—of Europe.

While this latter fact has been determined largely by paleobotanic[1] evidence and that derived from the cephalopods[2] it is believed that the trend of the evidence furnished by the invertebrates is, in general, in the same direction.

The Cherokee shales are a thick (400–500 feet) series of shales with some sandstones and coal, on the whole unfavorable to the existence of clear-water marine faunas. Indeed much of the region stood at about sea-level for considerable lengths of time, as is evident from the plant remains and coal deposits distributed through the rocks as well as by ripplemarks and other physical evidence. However, marine conditions and faunas appeared especially during its later history.

Following the deposition of the Cherokee shales the sea transgressed and the Fort Scott limestone was deposited. This limestone is of considerable thickness and carries a rich marine invertebrate fauna. Following the Fort Scott limestone there occurred rythmic recessions and transgressions of the clearer marine waters throughout the Kansas region, resulting in the deposition of alternate clay shales and limestones with, rarely, fine sandstones and coal. The shales vary from 40 feet to 200 or more feet in thickness, and the limestones from two to 40 or 50 feet in thickness. The shales are clayey, sometimes carrying considerable fine sand, and are gray to

[1] David White, *Mon. XXXVII, U. S. Geological Survey*, 1899.

[2] J. P. Smith, *Mon. XLII, U. S. Geological Survey*, 1903.

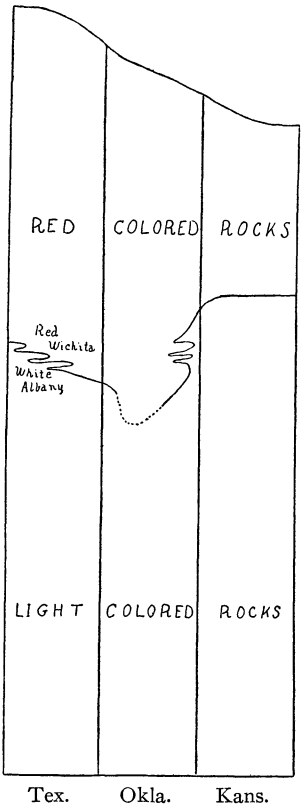
black in color. Blue, gray, and drab are the prevailing colors. The limestones are blue or gray weathering to a buff, and are sometimes nearly white. They are almost invariably well lithified, more or less crystalline, and are not very porous. The thickness of the whole succession, up to the Americus limestone, is over 2,000 feet or 2,500 feet, including the Cherokee shales.

The limestones do not all continue to the southern limit of Kansas, some of them pinching out before reaching the Oklahoma line and others soon after crossing it. Few of them pass beyond the Arkansas River in that state. It seems that the central part of the Kansas basin may have been to the northwestward during later Pennsylvanian time, since the shales frequently become thinner, and the limestones thicker in that direction, though this cannot be said of the lower part of the section. Above the Americus limestone the succession of limestones and shales continues for about 700 feet. However, the shales become more calcareous and marly, the limestones more porous and less crystalline; massive gypsum beds are intercalated, and coal in quantities is wanting. The limestones also weather white.[1] These changes are significant of decided physical or climatic changes, as the local pools of the lower horizons showed no tendency to concentrate and form massive gypsum deposits. Probably, also, the changed aspect of the limestones is indicative of these altered conditions. The first large deposits of gypsum occur just above the Cottonwood limestone in the lower part of the Garrison formation (Neosho member). Above these are the Wreford limestone, Florence flint, Fort Riley and Winfield limestones, heavily charged with chert, and separated by thick layers of shale. The outcrops of these formations form the "Flint Hills" of the eastern part of central Kansas. Over these strata are two soft limestones with three intervening shale beds and a variegated, brecciated, thin limestone. These are grouped in the Marion stage, and end the regular succession of limestones and shales. Over the rocks of the Marion stage lie the Wellington shales, probably several hundred feet in thickness, composed of blue, green, and some red shales. Upon these shales lie 1,400 feet of Red Beds in Kansas. The upper part of the Red

[1] Adams called attention to these lithologic features, in *U. S. Geological Survey, Bulletin 211*, pp. 70–78, 1903.

Beds does not occur in Kansas but is found in western Oklahoma and the Panhandle of Texas.

The whole of the lower succession of shales and limestones forming lowlands and low escarpments divide this section of continuous sedimentation into short stratigraphic units of great lateral extent convenient for paleontologic study.



In Oklahoma different conditions prevailed during much of the time represented by the Kansas deposits, above the Cherokee shales.

Passing from Kansas to Oklahoma the light-colored shales and limestones of the upper part of the Kansas section grade off into red shales and sandstones. The lowest horizon in Oklahoma at which the red sediments predominate is unknown, inasmuch as the strike of the rocks is but little west of south, and the Red Beds protrude eastward in central Oklahoma as a sort of embayment, especially north of the Arbuckle Mountains.[1]

In the region south of the western end of the Arbuckles the Red Beds lie unconformably upon the tilted and eroded Pennsylvanian rocks. It appears that the Albany-Wichita sea of northwest Texas transgressed over this region during a time of slight depression, the waters covering the western end of the Arbuckle Mountains, swinging eastward on their northern slope as far as the Seminole Country. According to Cummins there is no unconformity in Texas between the lighter

[1] For the citation and review of the literature on the Permian of Oklahoma and Texas, see the author's paper on the "Invertebrate Paleontology of the Upper Permian Red Beds of Oklahoma and the Panhandle of Texas," *Kans. Univ. Sci. Bull.*, IV, pp. 115–48, 1907. The geology of the Arbuckle and Wichita mountains is described by Mr. J. A. Taff in *Professional Paper 31, U. S. Geol. Surv.*, 1904.

sediments and the Red Beds, the transition between the Albany and the Wichita being a gradual lateral one. The transgression of the Red Beds in the Arbuckle Mountains may, then, be regarded as a northeastern or eastern encroachment of the Wichita sea—or conditions of sedimentation, as all these beds may not be marine. Whether this Arbuckle unconformity extends northeastward to the easternmost limit of the Red Beds has not yet been determined, and indeed may be very difficult to determine, where the unconformity would resolve itself to a mere disconformity of layers of shales, and perhaps accompanied by a greater or less reworking of the lower deposits. Gould, who has been over this region between the Arbuckles and the Arkansas River many times, states that he knows of no unconformity. If no unconformity exists to the north of the Arbuckle Mountains, it seems probable that the first Permian emergence began here and the deposition of the Red Beds in the Seminole Country is the first record of it, the later sediments from the Arbuckles reaching farther north. Regarding the gradation of the upper part of the Kansas section into the Red Beds in northern Oklahoma, there can be no doubt whatever, and the same is probably true of the central part of the state.

The Arbuckle and Wichita mountains are probably the source of much of the red sediment, in which they are partially buried, and the former mountains are directly responsible for the eastern extension of these beds into central Oklahoma. The extent to which the lighter-colored sediments of Kansas and Texas are replaced by red sediments in Oklahoma and near it, represents in a rough way the limits of the influence of these mountains on the deposits of the time by the spread of their sediments. By the time the deposition of the light-colored sediments had ceased the conditions had become such that nearly all the sediments derived from the land surrounding this basin were red.

In the Oklahoma region the deposition of red sediments began, perhaps, as low as the Howard or Topeka limestones, and perhaps as high as the Emoria or Americus limestones. The deposits then seem to be uninterrupted until the unconformity below the Dockum beds (Triassic) in the Texas Panhandle is reached. Some of these beds appear to be of subaerial origin, as has been shown by Case,[1]

[1] *Bull. Amer. Museum*, XXIII, pp. 659–64, 1907.

while others are certainly marine. Careful petrologic study will probably demonstrate that much of the arenaceous material is wind-blown sediment, more or less reworked by currents or waves as the regions were submerged or flooded. That the sea ever covered the entire area from Kansas to southern Texas and New Mexico at one time may be questioned. If it did, the sediments contained were of such a nature and abundance, or the waters so concentrated as to preclude the free migration of a normal marine fauna throughout the basin. That marine conditions prevailed, at least locally, is demonstrated by the Whitehorse and Dozier faunas.

In Texas normal deposits were laid down in higher horizons than in Oklahoma, and in Kansas there are reasons for believing that the light-colored sediments were laid down at an even later date than in Texas. These conditions are illustrated in the subjoined table, showing a vertical section of the Carboniferous and Permian rocks of the three states.

The extent of this post-Pennsylvania basin seems to have been very great. It included much of Kansas ($\frac{2}{3}$), Western Oklahoma, much of western Texas, and all of New Mexico, Colorado, and Wyoming east of the Rocky Mountain axis. In area it probably aggregated 300,000 square miles.

Together with the varied physical conditions of these three regions went corresponding faunal peculiarities. In the Albany division of the Texas rocks the Pennsylvanian elements of the fauna seemed to persist, while they are largely wanting in their equivalent beds, the Wichita division. A similar thing occurs in the clear-water beds of northern Oklahoma and southern Kansas, north of the Red Beds. Aside from this general fact it should be noted that along the region of the Red Beds and light sediment (litoral?) contact, some of the Pennsylvanian elements of the Kansas fauna persisted much longer than in the same rocks to the northward. The fauna of any given horizon above the Elmdale formation varies very sensibly as we pass from the Nebraska to the Oklahoma line, both in abundance of specimens and species, and in the general aspect of the faunules as well. This is to be expected in the light of the intercalation of massive gypsum beds as low as the lower part of the Neosho member in the northern region. From it we would infer that the waters of the

northern-main marine part of the basin were somewhat more concentrated than at its southern shore.

OUTLINE OF FAUNAL HISTORY

One of the most striking features of the Kansas Anthracolithic fauna is the great range of a relatively large number of species. In regions of instability of the earth each successive change of physical conditions brings in new faunas, tending to eliminate their predecessors, and bringing about more rapid and complete faunal changes than in interior regions of continental stability. In these latter regions the effects of these crust movements are minimized and their effect upon the faunas is proportionally less marked. Consequently one accustomed to the study of the faunas of marginal continental deposits may easily underestimate the value of the less complete faunal changes occurring in rather remote epicontinental basins.

In the regions of great instability it is rarely, if ever, that species show their whole life-history, from its inception to its natural termination, in an unbroken succession of rocks. In an interior region, like the Kansas basin under discussion, persistent species do occur exhibiting this life-history fairly completely, and are significant of the lapse of time represented by the deposits. Many of the forms which are so persistent in the Kansas rocks, especially among the brachiopods, represent the latest stages of the life-history of their genera or families which rarely, if ever, give rise to new phyla, since they have passed their culmination and entered upon their decline. They are therefore not to be expected to give rise to many new forms under ordinary conditions (in the higher deposits) and, having largely lost their adaptability, perish under untoward conditions. Under this class of organisms come the Productidae, Strophomenacea, and Orthidae, and the genera Seminula, Cleiothyris, Hustedia, Ambocoelia, Spirifer, and Pugnax, which are unknown above the Permian. Nearly all these groups have their maximum development in the Pennsylvanian or earlier deposits. Among the bryozoans this is still more strikingly true. The Fistuliporidae, Batostomellidae, Rhabdomesontidae, Fenestellidae, and Acanthocladiidae disappear before the initiation of the Mesozoic, and nearly all of them have culminated before the beginning of the Permian.

In strong contrast with the brachiopods and bryozoans stand some of the pelecypods. They are not paracmic and do differentiate with changing conditions, and constitute the main characteristics of the upper part of the Kansas section. This differentiation seems to have been in the main closely parallel in direction with the development of the Permian pelecypods of Europe.

It is to be regretted that the ammonoid cephalopods were nearly wanting in the Kansas basin throughout its faunal history. The trilobites are represented in the upper rocks by a single species of Griffithides, the last (so far as the Kansas rocks are concerned) of the Proetidae. Many of the ostracods are to be looked upon as degenerate or atavistic, and probably are not found above the rocks of the Chase stage.

The study of the stratigraphy of the Kansas basin and its surrounding deposits and its fauna, has convinced me that the foregoing general considerations must be taken into account in order to reach a rational understanding and interpretation of its faunal history. It should also be held in mind that the evolution of a fauna, in so far as it is capable of evolution, in this great epicontinental sea is of as great significance, as the evolution of a fauna along similar lines about the islands and in the continental seas of Europe. On account of its limitations and relative paracmic condition the latest fauna of the Kansas basin, without free contributions from other regions which physical conditions seemed to prohibit, cannot be expected to contain the wealth of species characterizing cosmopolitan faunas.

In the study of the Anthracolithic section of Kansas the following stages and larger divisions here designated "series" have been made out. These divisions with their characteristic faunas are described in Vol. IX of the Kansas survey, in press at this writing.

The basal formation of the Kansas Pennsylvanian system is the Cherokee shales or Stage A. This stage is characterized by a preponderance of specimens of *Marginifera muricata* with an abundance of *Chonetes mesolobus*, etc. It might with propriety be called the *Marginifera muricata* Zone, as in no other horizon is this species the predominating one. Stage B is characterized by the introduction of a very large number of the most characteristic Coal Measures fossils, sixty species being added in its basal member, the Fort Scott

	Series	Stage	
PERMIAN	V	Well.	Wellington shales
		Marion	Abilene conglomerate Pearl shales Herington limestone Enterprise shales Luta limestone
	IV	Chase	Winfield limestone Doyle shales Fort Riley limestone Florence flint Matfield shales Wreford limestone
		J	Neosho member } Garrison formation Florena shales } Cottonwood limestone
		I	Eskridge shales Neva limestone Elmdale formation
PENNSYLVANIAN	III	H	Americus limestone Admire shales Emporia limestone Willard shales Burlingame limestone Scranton shales
		G	Howard limestone Severy shales Topeka limestone Calhoun shales Deer Creek limestone Tecumseh shales Lecompton limestone Kanwaka shales
		F	Oread limestone Lawrence shales Kickapoo limestone Leroy shales Stanton limestone Vilas shales Allen limestone Lane shales
	II	E	Iola limestone Chanute shales
		D	Drum limestone
		C	Cherryvale shales Dennis limestone Galesburg shales Mound Valley limestone Ladore shales Bethany Falls limestone
	I	B	Pleasanton shales Coffeyville limestone Walnut shales Altamount limestone Bandera shales Pawnee limestone Labette shales Fort Scott limestone
		A	Cherokee shales

limestone, and fifteen during the rest of the stage. Nineteen of these fossils are among the best-known Pennsylvanian species, such, for instance, as *Campophyllum torquium*, *Rhombopora lepidodendroidea*, *Stenopora carbonaria*, *Chonetes verneulianus*, *Dielasma bovidens*, *Meekella striaticostata*, *Acanthipecten carboniferus*, *Aviculopecten occidentalis*, *Schizodus wheeleri*, *Euomphalus catilloides*, and *Tainoceras occidentale*. One of the peculiarities of this stage is the occurrence of Chaetetes reefs, especially in the upper Fort Scott limestone. Another characteristic is the appearance of Foraminifera with the form of Fusulina, but with imperforate shells, probably belonging to the genus Fusulinella. These conditions maintain themselves until the close of the stage.

These two stages combined make up a definite faunal unit of a larger order which I have designated as "Series I." Fusulinella and *Chonetes mesolobus* are confined to it, and *Marginifera muricata* is never so abundant again. *Chaetetes milleparaceous* is comparatively rare in the rocks above.

The early part of Stage C is marked by another great influx of species which is more continued than that of the preceding stage, though the species are hardly as important. It seems very probable that at this time there was quite as general a sea connection between the Kansas sea and the rest of the world as at any time during the history of the basin. Such important species as *Lima retifera*, *Sedgwickia granosum*, and *Orbiculoidea convexa* are among those introduced—over thirty species in all.

Stage D is the most striking horizon in the Kansas succession. Oölitic conditions with their accompanying fauna invaded the region and give us a peculiar assemblage of fossils, some of which seem quite foreign to their surroundings. We have in the Drum limestone, or its equivalent, at Kansas City and vicinity, a well-developed Pseudomonotis fauna. These fossils usually characterize the Permian rocks of Europe. They are here found in rocks far below the Permian. Unlike the faunas of the rocks above and below, this fauna is strongly molluscan. Many of the species introduced disappeared with the muddying of the waters, while others returned intermittently, especially the species of Pseudomonotis which became very prominent in the Permian rocks.

Stage E forms the closing chapter of the conditions existing in these rocks. Here several of the species with which we have been dealing are found for the last time, examples being *Michilinia eugeneae, Conocardium parrishi, Lima krotowi, Cryptacanthia compacta,* and others.

These three stages make up Series II. It is characterized by the features already mentioned and in a negative way by the absence of species of extreme importance noted below, which occur in the rocks above.

Stage F is characterized by the absence of the species just mentioned and the introduction of *Chonetes granulifer,* one or two species of Enteletes, and the true Fusulinas. Some of these fossils color nearly every faunule of the succeeding rocks of the Pennsylvanian part of the section. . Among other important species introduced were the Amblysiphonellas and other sponges, *Limopteria marian,* etc. The top horizon of the stage is remarkable for the last appearance of twenty species, and the first important development of the Fusulinas, a long, slender species, and the first abundance of *Chonetes granulifer.*

In Stage G an undescribed species of Strophalosia is the only permanent addition, while the loss of species amounts to twenty-eight (disregarding species peculiar to the stage), most of these being found for the last time in the Howard limestone, its topmost member. Among these are many prominent Pennsylvanian species, as *Squamularia perplexa, Productus pertenuis, Campophyllum torquium,* etc.

In Stage H, *Sedgwickia altriostrata* is added in the Burlingame limestone and Bairdia, Beyrichiella, and Meekopora appear in the uppermost bed. These latter additions may be well associated with the succeeding stage as they are found in the marly layer resting upon the Americus limestone, and are the precursors of other important introductions which follow.

Stages F, G, and H comprise Series III. From what has preceded it is seen to be characterized by the introduction or development, in its basal part, of three of its main faunal elements and is set off from the succeeding series by the fact that at least one hundred and seventy-five of its species are unknown in the rocks above.

In Stage I four species first appear which play a very important

rôle in the later faunas. They are: *Pleurophorus whitei, Aviculopicten nebraskensis,* and *Myalina permiana* and a species usually referred to *M. aviculoides.* A species of Schwagerina associated rather closely with a Permo-Carboniferous micro-foraminiferal fauna also occurs in this stage. During this stage, too, some of the most characteristic and cosmopolitan species of the Kansas Pennsylvanian are found for the last time. Four of these are: *Spirifer cameratus, Hustedia mormoni, Spiriferina kentuckiensis,* and *Chonetes geinitzi* (not *C. laevis* of Keyes).

Stage J is important in that it records the final reduction of the Fusulinas to the ranks of a rare species, in possessing a very abundant ostracod fauna of a late type, and the final occurrence of ten or fifteen species.

The Chase stage, the upper part of Series IV, is characterized by the development of the pelecypods and the lessening of the rôle played by the Molluscoidea. The abundant forms are: a retrogressive form of *Seminula argentia,* a species of Fenestella, *Productus nebraskensis, Bairdia beedei* or an allied form, with other ostracods, *Septopora* sp., *Derbya multistriata, Mylina permiana, Aviculopecten nebraskensis* and a form of *A. occidentalis, Myalina aviculoides?,* several species referred to Bakewellia, *Pleurophorus whitei,* with two other species, *Pseudomonotis hawni, Edmondia nebraskensis, Aviculopinna knighti, A. nebraskensis,* Producti of the *semireticulatus* type, and a Derbya like *D. crassus* and a species of Rhombopora.

Above Series IV, the brachiopods and bryozoans and ostracods and other lower groups nearly disappear, leaving an impoverished pelecypod fauna. The fauna of the Red Beds of Oklahoma and the Panhandle of Texas, lying one or two thousand feet above the Marion stage, has already been described.[1]

The following table is expressive of the numerical relationship of Series IV to Series I–III:

	No. of Species		No. o Species	Species in Common
Series I	131	Series IV	141	51
Series II	237	Series IV	141	73
Series III	264	Series IV	141	85

[1] "Invertebrate Pal. Upper Permian Red Beds of Oklahoma and Panhandle of Texas," *Kansas University Sci. Bull.,* IV, pp. 115–71, 1907.

These figures are by no means expressive of the faunal character of Series IV, especially the part lying above Stage J. The nature of this fauna is such as to separate it sharply from any Pennsylvanian fauna known to me. For the characteristic fossils of the series as a whole we must add the "Permo-Carbon" micro-foraminiferal fauna described by Spandel,[1] probably from the Neva limestone, *Orbiculoidea manhattanensis, Pugnax swallowana* (Hall and Clarke's identity), *Meekopora prosseri,* and *Thamniscus octonarius.*

Considered as a whole the fauna of Series IV, however closely or remotely the individual species may be related to those of other regions, certainly exhibits the same general aspect as the Permian (including the Artinsk and Permo-Carboniferous) of England, Germany, and Russia.

Series IV is regarded as the equivalent of the Permo-Carboniferous of Europe which is classed by most European geologists as the lowest division of the Permian. Stages I and J are, perhaps, debatable ground on account of the great preponderance of Pennsylvanian species. However, the loss of 179 species (two-thirds its fauna) during the latter part of Series III and the introduction of distinctive Permian elements are considered as strong evidence pointing to the initiation of Permian conditions. If this is supplemented by similar plant evidence it should be referred to the Permian.

The Wellington is unquestionably referable to the Permian in the narrowest sense of the word and the Marion probably may be.

THE NORTH URALIAN SECTION

The Anthracolithic section of the Ural-Timen region of northeastern European Russia is as follows: The "Middle Carboniferous," Omphalotrochus horizon, Productus-Cora horizon, Schwagerina horizon, Artinskian, and Permian. The Artinskian constitutes the "Permo-Carboniferous" of Russia. The uppermost division of the Carboniferous is the Schwagerina horizon below which is the Productus-Cora—"Cora" of Tschernyschew—horizon. These two are sometimes referred to as the Fusulina limestone, and the lower as the Gschelian. Below them lies the Omphalotrochus horizon

[1] "Die Foram. des Permo-Carbon von Hooser," *Kans., N. Amer., Abhl. der Naturh. Gesellsch. in Nürnberg,* pp. (on separate) 1–20, 1901.

and beneath it the "Middle Carboniferous." The Artinsk is considered as a subdivision of the Permian.

The part of the section of particular interest to us is the portion including the "Cora," Schwagerina, and Artinsk zones. The relationships of these Upper Carboniferous beds of the Urals to the Artinsk is clear. The sandstones and conglomerates of the latter rest directly upon the calcareous deposits of the former. As has been so well shown by Krasnopolsky, the Permian period of eastern Russia is especially characterized by the uplift of the Ural Mountains from a series of islands to a continuous mountain chain. In the northern part, the Ural-Timen region—including the Timen Mountains—it was rapid and sandstones and conglomerates on the western flanks were the result. This permits a sharp differentiation of the deposits. In the southern region this sharp distinction is impossible as the uplift was very slow and the effects less noticeable, gypsum and dolomites being about the only lithologic indications of the changing conditions in the Donnez basin. In the north there is a sharp differentiation of the fauna in response to the sharply changed physical conditions, while in the south the differentiation is correspondingly more gradual and is produced by the mingling of the northern species of the Artinsk with the open-sea fauna of the Carboniferous. This makes the line between the Permian and Carboniferous harder to draw in the southern region. As Krasnopolsky argues,[1] the place to draw the line is with the first appearance of the Permian species. The conditions in northern Oklahoma, Kansas, and Nebraska were very similar to those of the southern Ural region.

As Rothpletz[2] has pointed out, and as further discussed by Diener,[3] the arenaceous fresh- and salt-water deposits of the Ural-Timen region and the Zechstein are not the normal open-sea deposits of the Permian period, but somewhere those conditions existed in which the percentage of Carboniferous elements in the fauna would be larger. They also point out that these deposits probably are to

[1] *Mem. Geol. Comm. Russ.*, Vol. IX, pp. 506 ff.

[2] Rothpletz, "Die Perm-Trias u. Juraform. auf Timor, etc.," *Paleontographica*, XXXIX, pp. 57 ff., 1892.

[3] "Diener, Himalayan Fossils," *Mem. Geol. Surv. India, Pal. Indica.*, Ser. XV, Vol. I, 1899–1903.

be found in the Asiatic region and in America. To a fair degree this seems to be true of the lower portion of the Permian (that part represented in the Kansas section) in America, and as Diener has shown, in the eastern Himalayas, and it is true of the Mediterranean region. The most typical marine Permian fauna of this age in America is found in the Guadalupe Mountains of Texas and New Mexico.[1] It is the failure to recognize these dual conditions that has caused much of the controversy over the Permian question.

In the Kansas rocks as well as those of Oklahoma and Texas, only the basal part is typically marine. The typical marine facies of the beds extend quite as high in the Kansas section as in that of Texas. Local incursions of marine conditions occur later in western Oklahoma and Texas than in Kansas.

The faunal relationships of the Kansas section are such as to lead us to suspect that an interrupted intermigration requiring considerable time in its consummation occurred between the European and Kansas regions. This fact tends to complicate direct correlation and it is questionable if minor stages can be correlated closely with those of Europe. Less trouble will probably be encountered in the final determination of the separation of the Permian—in the broad sense of the term.

COMPARISON OF FAUNAS

A collection of Foraminifera, probably from the Neva limestone, was studied by Erich Spandel.[2] Some of these were found to be distinctly of Carboniferous and some of distinctly Permian affinities, and he concluded that the rocks from which they come are of Permo-Carboniferous age. He was sufficiently sanguine of this to name two of the species "postcarbonica." The species described are: *Ammodiscus concavus, Bigenerina* cf. *eximia, Dentalina bradyi, Geinitzina postcarbonica, Lituola?* sp., *Monogenerina atava, M. nodosariforsis, Nodosaria postcarbonica, Tretaxis conica,* and *Textularia gibbosa.* Probably from the same stratum from which these Foraminifera came, we find specimens of a typical *Schwagerina.* The same stratum

[1] Girty, "The Guadalupian Fauna," *Professional Paper 58, U. S. Geological Survey,* 1909.

[2] *Loc. cit.*

farther south has furnished us with an abundance of Fusulina very similar to, if not identical with, *F. longissima*. It is worthy of note that Schwagerinas and *F. longissima* are associated in some of the European deposits, but among somewhat older faunas. When we consider that Schwagerina is totally unknown in the Atlantic province and consider the route which it must have taken in reaching this region—Eastern Himalayas, China, California—it is but natural to expect it to appear in a somewhat higher horizon than that from which it started, since it is improbable that all the barriers of Eurasia and America were removed to furnish it simultaneous passage. For this reason its appearance among an open-sea Permo-Carboniferous micro-foraminiferal fauna of the Atlantic province may be explained. It should be remarked, however, that some species of Schwagerina are found in rocks of Permo-Carboniferous age in Eurasia.

Of the sponges there are two genera worked out, that permit of direct comparison. They are Amblysiphonella and Steinmannia. *Amblysiphonella prosseri*, from the Topeka limestone in Kansas and a horizon not any higher at Weeping Water, Nebraska, is closely allied to a species from the Lower Productus limestone or Amb beds of the Salt Range in India, while Steinmannia described by Dr. Girty from the Allen limestone seems to have a close relative in the specimens of that genus in the Middle and Upper Productus limestone of the Salt Range. The fact of peculiar interest is that the relative positions of the two in Kansas is reversed from what it is in India, Amblysiphonella occurring at a higher horizon than Steinmannia.

There are two species of corals common to the Kansas section and the Artinskian—Dolomite Suite—of the Donnez Basin of southeastern Russia: *Michilinia eugeneae*, which is confined to Series I and II in the Kansas rocks, and *Lophophyllum profundum*, occurring, probably, throughout the section from Series I to IV inclusive.

Several of our brachiopods appear to have relatives abroad. *Chonetes mesolobus* and *C. laevis* (not *C. geinitzi*) occur in the Schwagerina horizon in the Ural-Timen region, while in Kansas they are confined to Series I, and are separated from Schwagerina by 1,800 feet of deposits. *Chonetes variolatus* and *C. verneuilanis* are found in the Cora and Schwagerina horizons and in the Kansas section are

confined to the rocks below Series IV. *Chonetes granulifer* has a similar range in the Uralian deposits, but begins in the Allen limestone and continues into the Florence flint in the Kansas rocks. *Spirifer cameratus*, *Spiriferina kentuckiensis*, and *Hustedia mormoni* or a near relative of it are found as high as the Schwagerina limestone, and two of them, or their near allies, occur throughout the Artinskian and Permian in Russia. In the Kansas succession Spiriferina reaches the Elmdale formation, and the other two the Neva limestone. Two of them range through the whole Salt Range deposits. *Cryptacanthia compacta* or a species almost identical with it ranges through the Russian deposits into the Artinsk, and is confined to Series I and II of our section. Cleiothysis has a similar range in Europe, throughout the Permian in Asia, and to the Fort Riley limestone in the Mississippi Valley region. Shells of types of *Productus boliviensis* and *P. lineatus* are associated with the rocks from the Allen to the Oread limestone. Their Russian range is from the Cora to the Artinsk inclusive. *Productus cora*, in the strict sense, is probably confined to the rocks below the Deer Creek limestone, and those above are referable to Norwood's *P. pratteni* which continues to the Permian. In Europe *P. cora* ranges into the Artinsk. *Productus gruenwaldti* and *P. punctatus* range through the Artinsk, and are unknown above the Howard limestone of our section. *Productus nebraskensis* is quite as abundant in Series IV as at any horizon below, while (as understood by Tschernyschew) it is confined to the Omphalotrochus horizon.[1] However, its near relative ranges through the Artinsk. *Dielasma bovidens* occurs up to the base of the Wreford limestone and through the Schwagerina limestone of the Urals. The species of Squamularia are hard to differentiate and, with their allies, are ubiquitous throughout Eurasian Anthracolithic rocks. They are unknown above the Howard limestone.

[1] In the original description this species was supposed to be a sharp-beaked form. On the contrary it is an attached form, in its early stages presenting nearly every characteristic of a true Strophalosia, except that the adductor scars are arborescent. Mr. Greene, who is working on this species, has not yet completed his studies and it cannot be stated yet whether this character is a case of parallel development, or whether this is a species of Productus which has taken on the habit of attachment in its young stage. If the latter be true, it is the only case of an attached Productus with which I happen to be acquainted.

Pugnax utah is confined to the Schwagerina horizon on the one hand and in our rocks is ubiquitous, ranging from the Cherokee shales to the Fort Riley limestone. These remarks are also true of *Ambocoelia planoconvexa* which is common to the whole Indian Permian. Our ubiquitous *Derbya crassa* seems to be confined to the Omphalotrochus-Cora horizons. Jakowlew has recently shown that *Meekellia striaticostata* is synonymous with *M. eximia*, which makes it ubiquitous in both Russia and America.

All the pelecypods mentioned below have been found in the Permo-Carboniferous of the Donnez, Oka, and Kljasma basins of Russia as described by Jakowlew. Only their range in the Kansas deposits will be mentioned.

Pseudomonotis is a group of shells for the most part confined to the Permian deposits of the world, though running over into the Mesozoic. Nearly all the known species of it found in America are found in the Drum limestone, Stage D of the Kansas succession. They occur again in the Kickapoo limestone and become especially abundant and characteristic in Series IV and above.

These remarks apply in a general way to *Pleurophorus subcostatus*, the American equivalent of *P. costatus*. *Lima krotowi* or its affine is confined to Stages I and II. *Acanthipecten carboniferus* is confined to Series I and II and Stages F and G, except a specimen found at a much higher horizon in northern Oklahoma last fall. *Entolium aviculatum* has been recorded by Dr. Girty from the Wreford limestone. *Pleurophorus oblongus* has only been reported from the Drum limestone by Dr. Bennett. *Edmondia Nebraskensis* ranges from the Drum limestone well into the upper part of Series IV. *Schizodus wheeleri* is found from the Dennis limestone (and perhaps from the Fort Scott limestone) into the upper part of Series IV. Streblopteria is known from the Drum limestone to the Fort Riley limestone, Dr. Girty recording it from the latter horizon. *Pleurophorus subcuneatus* is unknown below Stage J. The Bakewellias and Cyrtodontarcas have not yet been faunally worked out. A species has been recorded from the Willard shales. However, they are very rare until much higher strata are reached.

It will be noted that in the faunal comparisons and discussions, the Chase and Marion stages have not been treated quite so fully as

those of the underlying horizons. The reason is that the faunules have not been quite so fully worked out and tabulated. However, they have been gone over in a preliminary manner and found to contain nothing, so far as I have observed, that is contradictory to the evidence presented.

From the foregoing discussion of the Kansas faunas and the comparison of the elements in common (for it is largely upon the elements in common that intercontinental correlations must be based) with those of Russia, there seems little reason for considering the Kansas faunas of Series III older than the Schwagerina-Cora horizons of Russia. Indeed the evidence is quite as strong in the opposite direction.

GENERAL SUMMARY AND CONCLUSIONS

From what has been said it is apparent that during the Carboniferous period on the continents of Europe and America there was a long period of time during which favorable conditions obtained and the fauna was relatively varied, but, as many of the genera and species became paracmic, they were, in varying degrees, unable to adjust themselves to the changing conditions introduced more or less gradually with the Permian, and perished. Those capable of least resistance perished first, and in the basal Permian we have a fauna made up of two elements in response to the physical and biologic conditions. First, the hardier forms which had passed their culumation and were on their decline. This is especially true of the brachiopods. They disappeared, not more, perhaps, from want of favorable conditions than from loss of vitality. Second, the pelecypods differentiated—possibly receiving recruits from other regions—and became the characteristic forms of the Permian.

The one part of the Pennsylvanian fauna "grew old and died" assisted by changing conditions, while that part which had not previously reached the acme of its existence differentiated into a fauna capable of inhabiting the more and more concentrated waters of the Permian seas. These classes of organisms being similar on the two continents produced similar results, whether or not the species were identical.

We may now summarize the bearing of the evidence of the stratig-

raphy and the invertebrate fossils on the age of the rocks under the following seven heads:

1. The physical conditions and climatic history of the Permian of America and Europe were similar. They were marked by the deposits of dolomites, limestones, gypsum, and red sediments on both continents.

2. The upper Pennsylvanian sediments were in each case marked by a superabundance of Fusulinas, and by other similar faunal elements.

3. The fauna of the lower Permian—including the Artinsk—is characterized by the development of a peculiar molluscan element and its dominance over the Molluscoidea.

4. The general comparison of the elements in common in the upper Pennsylvanian faunas indicates that Series III is as young as the uppermost Carboniferous faunas of Europe.

5. The great reduction of Pennsylvanian species near the close of Series III and the base of Series IV, together with the introduction of species in the basal part of Series IV which become very important and characteristic elements in the faunas of the higher rocks, seems to justify the provisional location of the Pennsylvanian-Permian boundary at the base of Series IV.

6. The general similarity of the faunas of Series IV and the overlying rocks of the Kansas basin with the Permian of Europe seems to be suggestive of their homotaxy.

7. The extent of Permian time represented in the Texas Panhandle region by the unconformity of the Permian Red Beds and the Triassic Dockum beds is unknown.

What the final evidence of the fossil vertebrates and plants may be remains, to some extent, to be determined. With the rapid progress now being made in the study of the former on both continents and the rapid collection of the plants now in progress in the western Mississippi basin, we may look in the near future to a fuller determination of the homotaxy of American and European Permian. In the meantime I am inclined to take the evidence of the physical conditions and the invertebrate fossils at its face value and draw the conclusions in accordance with it.